2013

# Estimation of rock cavability in jointed roof in longwall mining

Alireza Jabinpoor
*University of Tehran*

Ahmad Jafari
*University of Tehran*

Mehdi Yavari Shahreza
*University of Tehran*

# ESTIMATION OF ROCK CAVABILITY IN JOINTED ROOF IN LONGWALL MINING

Alireza Jabinpoor[1], Ahmad Jafari[2] and Mehdi Yavari Shahreza[2]

*ABSTRACT:* Longwall mining is one of the major methods in the coal mining industry. A main concern in this method is roof cavability and caving step or required advance length to make the roof to cave; this is specifically important when roof is relatively hard and caving is controlled by discontinuities within the roof rock. In this research roof caving is studied for different advances and various specifications of discontinuities. A rating method is suggested to characterize the rock mass based on the developed models. A graph has been constructed using the proposed rating system, which can be utilised to predict necessary caving step for the roof.

## INTRODUCTION

Caving methods are one of important category of methods which can compete with surface mining from productivity point of view. Among them, longwall mining is one of the major methods in the coal mining industry (Hartman, 2002). A major concern in the longwall method is the cavability of roof in a way to guarantee safety as well as optimum load imposed on the support equipment. To ensure appropriate caving of roof information about cavability of a given rock I needed. Successful caving depends on appropriate planning and stope design (Hardwick, 1965) Rock cavability depends on a number of factors e.g. rock structures *in situ* stresses, induced stresses in the caving area and rock mass classification (Laubscher, 1994; 2000). Thus rock cavability can be predicted base on these parameters. Vast use of caving mining methods has increased the importance of understanding rock cavability aspects in mine design. Prediction of cavability is a complicated task which has been the focus of many researches; most of the attempts have been based on experiences of different mines and data gathered from the field. However, development of numerical methods has shaped another possible approach for solving this problem and developing a different method of prediction.

## CAVABILITY PREDICTION

### Experimental approach

This approach is based on analysis of experienced obtained from field by different people. Among most popular approaches of this kind are the Mathews and Laubscher methods. They generally apply classification methods to rock and propose a relationship between rock rating and rock hydraulic radius.

***Mathews methods:*** Mathews *et al.,* (1980) proposed his method using data obtained from his studies in open stopes (Suorieni, 2010). He proposed calculation of stability number (N), to be used for cavability prediction, as follows:

$N = Q' \times A \times B \times C$
While $Q' = (RQD/J_n) \times (J_r/J_a)$

The three correction factors A, B and C represent stress factor, joint defect orientation factor and gravity factor respectively and can be determined using graphs proposed by Mathews. Figure 1 shows the cavability of rock depending on stability number and hydraulic radius (ratio of area to perimeter of a rectangular) of opened area. According to Mathews proposal three different zones, i.e. stable zone, potentially unstable zone and potentially caving zone can be distinguished. Later, some attempts were made to improve Mathews proposed method. The latest study (Brown, 2003) has considered additional data from 400 mines, result of which is shown in Figure 2, the same three zones can be seen in this figure. It should be noted that hydraulic radius is characterizing the open area but does not include opening height.

[1] *Graduate Student, School of Mining Engineering, University of Tehran*
[2] *Ass. Professor, School of Mining Engineering, University of Tehran*

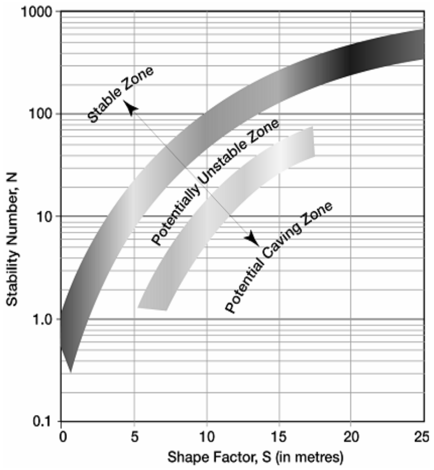


**Figure 1 - Rock cavability for different stability number and hydraulic radius (Mathews, *et al*., 1980)**

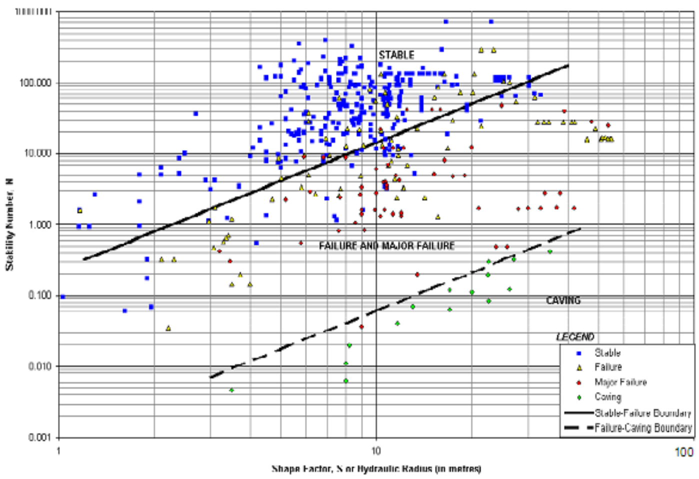


**Figure 2 - Corrected rock cavability (Mawdesley, 2002)**

***Laubscher method:*** Laubscher (2000) has started a series of investigations in this area since 1977. He first divided the rock mass into five groups based on geomechanical parameters. He then introduced the new approaches based on Mining Rock Mass Rating (MRMR) and *in situ* Rock Mass Rating (IRMR).

MRMR is developed based on RMR by applying four correction factors for weathering, joint orientation, mining induced stresses and blasting. IRMR was later introduced in 2000. One major change was discarding RQD from the classification; Figure 3 shows the final cavability prediction graph proposed by Laubscher which is based on the MRMR value of the rock and the hydraulic radius of the open area. This figure, similar to Mathews method, divides the rock into three categories i.e. stable, caving and transitional zone

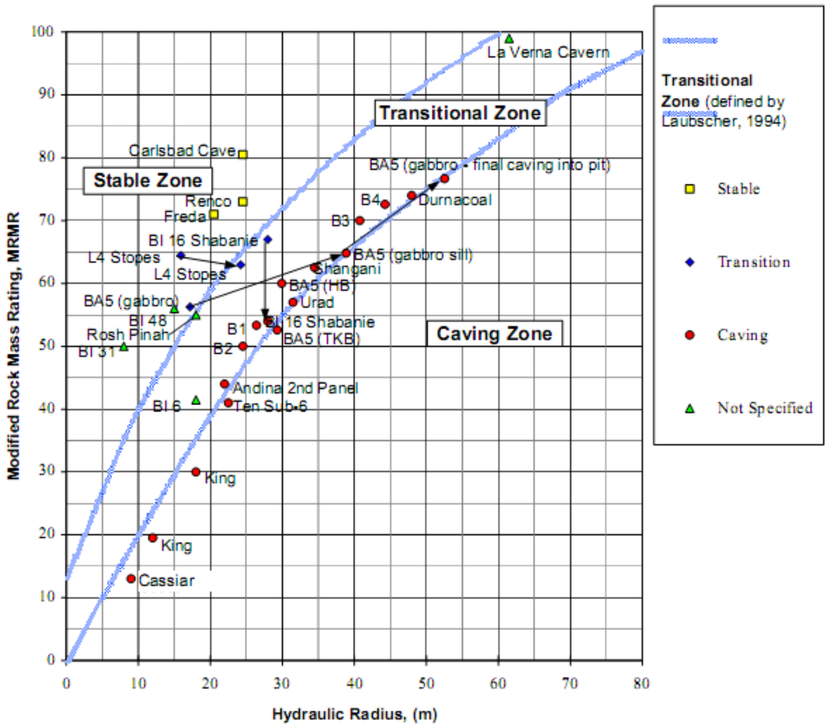


**Figure 3 - Rock cavability prediction (Mawdesley, 2002)**

Both described methods show that when rock quality is better a higher hydraulic radius is required to force the rock to cave. Higher hydraulic radius can be practically obtained by increasing the minimum span of the area i.e. width of the stope in longwall.

**Numerical approach**

Numerical approaches use the advantage of applying mathematical relationships between rock elements and blocks and combining them towards problem solution. Tollenear (2008) and Vyanzmensky (2008) have shown application of these methods in characterizing caving procedure.

In general such modelling can be done using continuous or discontinuous simulation. Considering the effect of discontinuities on rock caving especially for harder rocks, the latter method is preferable and used in this research. The code UDEC (Itasca, 2000) is proper available software for such modelling. This code can accommodate large displacement and block rotation which is inevitable for caving simulation.

## LONGWALL MODELLING

The modelling was done in two dimensions and a Mohr coulomb failure criterion was used for the rocks. Figure 4 shows the general geometry of the model. Displacement of roof was monitored and cavability was judged based on the amount of displacement for different spans. Cavability is considered to be controlled by two factors, rock displacement and span size. More displacement in smaller span means good cavability and vice versa.

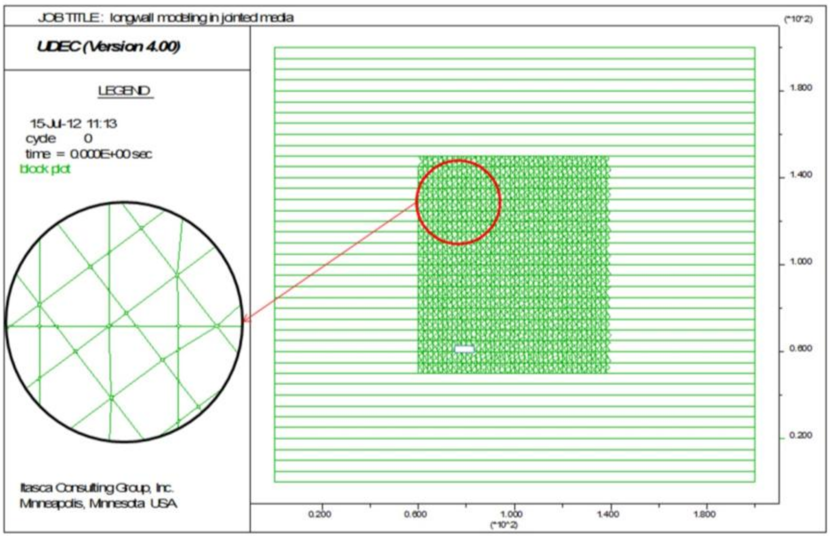


**Figure 4 - General geometry of constructed model**

The model size is 200 m x 400 m, however to decrease computation time, only the central part was jointed. Comparison with a fully jointed model shows the results are very much similar. The central part of the model is subject to four joint sets. To make the roof cave, the stope was advanced in 2 m steps. As the stope was advanced the displacement of roof was monitored. A vast number of models were tested to evaluate the effect of four major parameters of joints i.e. spacing, dip angle, friction and cohesion. These parameters were found to be the main controlling factors for cavability, details of which are discussed below:

**Joint spacing:** This parameter indicates block sizes in rock mass which in turn affects the failure and caving of roof. Figure 5a shows the effect of joint spacing on roof displacement which is an indication for cavability. The figure depicts stability increases for larger spacing.

**Dip angle:** Dip variation is studied for dip magnitude between 20 and 80 degrees; figure 5b shows the results. As can be seen when the dip angle is 45˚, large displacement happens in smaller spans. In general cavability is better for less dipped jointed rock.

**Joint friction and cohesion:** Shear strength is an important factor affecting displacement, which is controlled by friction angle and cohesion. As can be seen in Figure 5c, by increasing friction angle rock joints become stronger against shearing thus cavability decreases. In other words larger spans are needed for roof to cave. Figure 5d similarly shows the cohesion effect. As is expected an increase in cohesion, increases shear strength of joints and stability, thus roof may only cave by increasing the opening span.

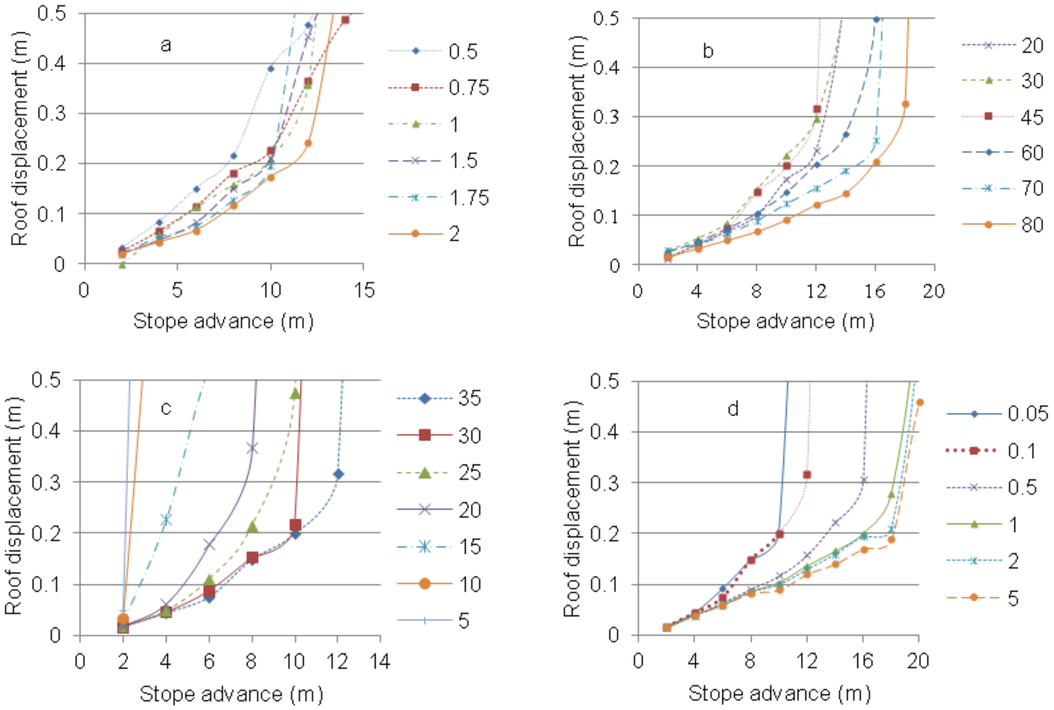


**Figure 5 - Effect of a) joint spacing, b) joint dip, c) joint friction, d) joint cohesion, variation on roof displacement**

## CAVABILITY PREDICTION

Results of the modelling show that displacement and cavability is determined and controlled by different factors. It is necessary to combine these different effects. For this purpose a rating system was employed to allocate different weights to each parameter. Five different rating systems were tested using studied parameters, shown in Table 1; total rating is 100 for each state of rating. First state shows uniform distribution of total rating for different factors while the importance of each factor is different in the other four states of rating. Higher value of total rating indicates more stable rock and less cavability. Tables 2 to 5 show rating distribution for each of the four parameters. Joint spacing is divided into five categories while dip is considered into three.

The ruling dip of the joint sets is considered in the analysis. Joint cohesion is stated as a percentage of rock cohesion and it can be maximum equal to rock cohesion.

Caving is assumed to happen if rock displacement is more than 50 cm while the rock with displacement less than 15 cm is assumed as stable. No judgment is made for the intermediate conditions. Figure 6 shows the produced graph which determines the cavability based on proposed rock rating and opening span. This figure is based on first state of rating mentioned in Table 1. Other rating states result in similar graphs.

**Table 1 - Joint parameters under study and allocated rate**

| Parameter | Rate | | | | |
|---|---|---|---|---|---|
| | State 1 | State 2 | State 3 | State 4 | State 5 |
| Spacing | 25 | 30 | 30 | 40 | 40 |
| Dip angle | 25 | 25 | 20 | 20 | 25 |
| Friction angle | 25 | 30 | 30 | 20 | 20 |
| Cohesion | 25 | 15 | 20 | 20 | 15 |
| Total rate | 100 | 100 | 100 | 100 | 100 |

**Table 2 - Allocated rate for joint spacing**

| Class | Spacing (m) | Rate | | | | |
|---|---|---|---|---|---|---|
| | | Sate 1 | State 2 | State 3 | State 4 | State 5 |
| I | S≥2 | 25 | 30 | 30 | 40 | 40 |
| II | 1.5<S<2 | 20 | 24 | 24 | 32 | 32 |
| III | 1<S<1.5 | 15 | 18 | 18 | 24 | 24 |
| IV | 0.5<S<1 | 10 | 12 | 12 | 16 | 16 |
| V | S≤0.5 | 5 | 6 | 6 | 8 | 8 |

**Table 3 - Allocated rate for dip angle**

| Class | Dip (degree) | Rate | | | | |
|---|---|---|---|---|---|---|
| | | State 1 | State 2 | State 3 | State 4 | State 5 |
| I | 50-90 | 25 | 25 | 20 | 20 | 25 |
| II | 0-40 | 15 | 15 | 10 | 10 | 15 |
| III | 40-50 | 5 | 5 | 1 | 1 | 5 |

**Table 1 - Allocated rate for friction angle**

| Class | Friction angle (degree) | Rate | | | | |
|---|---|---|---|---|---|---|
| | | State 1 | State 2 | State 3 | State 4 | State 5 |
| I | ≤10 | 5 | 1 | 1 | 1 | 1 |
| II | 11-20 | 15 | 10 | 10 | 7 | 7 |
| III | 21-30 | 20 | 20 | 20 | 14 | 14 |
| IV | ≥31 | 25 | 30 | 30 | 20 | 20 |

**Table 5 - Allocated rate for cohesion**

| Class | Cohesion | Rate | | | | |
|---|---|---|---|---|---|---|
| | | Sate 1 | State 2 | State 3 | State 4 | State 5 |
| I | $C_j \geq C_j$ | 25 | 15 | 20 | 20 | 15 |
| II | $0.7C_r < C_j < C_r$ | 20 | 12 | 16 | 16 | 12 |
| III | $0.5C_r < C_j < 0.7C_r$ | 15 | 9 | 12 | 12 | 9 |
| IV | $0.3C_r < C_j < 0.5C_r$ | 10 | 6 | 8 | 8 | 6 |
| V | $0.1C_r < C_j < 0.3C_r$ | 5 | 3 | 4 | 4 | 3 |
| VI | $C_j \leq 0.1C_r$ | 1 | 1 | 1 | 1 | 1 |
| $C_r$ = Rock cohesion, $C_j$ = Joint cohesion | | | | | | |

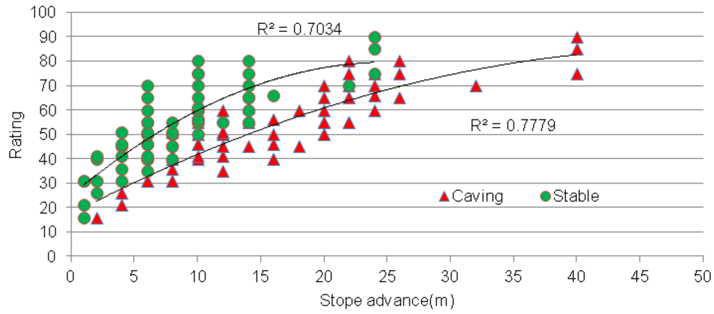


**Figure 6 - Cavability prediction by equal rating of four joint parameters**

It should be noted that variation of depth and stress state is not considered in these modelling and resulting graph.

When four input parameters (spacing, dip, friction angle and cohesion) were used in rating system third state of the rating, i.e. 30, 20, 30, 20 produced best result, judging by correlation coefficient. Figure 7 shows the final proposed graphs for cavability prediction based on both rating systems. For each rating two spans can be determined which indicate the stable roof and caving conditions. The spans between these two marginal figures can be considered as transitional. When the span is increased beyond a certain size the effect of roof strength on caving becomes less.

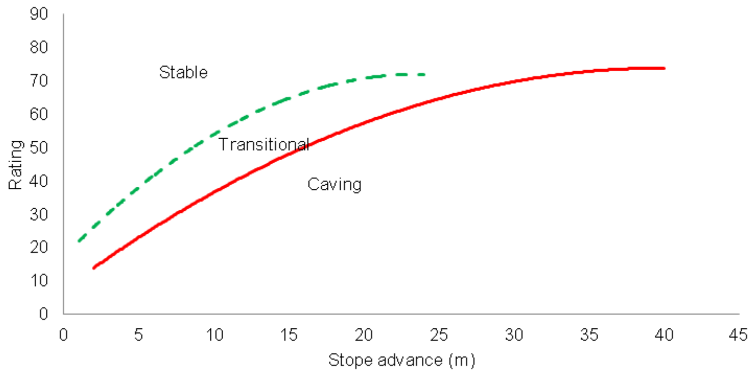


**Figure 7 - Proposed graph for cavability prediction**

## CONCLUSIONS

The longwall method is one of the major coal mining methods in which roof caving is an important issue affecting safety and performance of mining operations. During the mining procedure, when the roof is hard, caving is basically controlled by joints and its properties. It is important to know the minimum span required for caving for different conditions. A series of models were constructed and run to evaluate stability and/or caving of the roof when joint spacing and specification change.

Some graphs were produced based on a proposed rating system. Joint properties, i.e. spacing, dip, friction angle and cohesion were input in the rating system which resulted in a design graph. Based on the proposed graph it is possible to evaluate the required span for caving by knowing the rock rating from the proposed method. This rating system gives a simple means for evaluation of rock cavability.

## REFERENCES


Brown, E T, 2003. *Block Caving Geomechanics.* Queensland: Julius Kruttschnitt Mineral Research Centre Isles, 516p.

Hardwick, W R, 1965. Block-caving copper mining methods and costs at the Miami mine. US. Dept. of the Interior, Bureau of Mines. Washington: Miami Copper Company.

Hartman, Howard L, 2002. *Introductory Mining Engineering*, John Wily and sons, 584p.

Laubscher, D H, 1994. Cave mining-the state of the art, *The Journal of The South African Institute of Mining and Metallurgy*, 94:279-293.

Laubscher, D H, 2000. *A practical manual on block caving,* Prepared for International Caving Study, JKMRC and Itasca Consulting Group, Brisbane, 500p.

Mathews, K E, Hoek, E, Wyllie, D C and Stewart, S B V, 1980. *Prediction of stable excavation spans for mining at depths below 1000 meters in hard rock*. Golder Associates Report to Canada Centre for Mining and Energy Technology (CANMET), Department of Energy and Resources, Ottawa, Canada.

Mawdesley, C, 2002. Predicting cave initiation and propagation in block caving mines. PhD thesis (unpublished), University of Queensland, Brisbane.

Suorieni, F T, 2010. The stability graph after three decades in use: Experiences and the way forward. 4, Taylor and Francis, *International Journal of Mining, Reclamation and environment,* 24:307-339.

Tollenaar, R N, 2008. Characterisation of discrete fracture networks and their influence on cavability and fragmentation, MSc thesis (unpublished), University of British Columbia, Canada.

Vyanzmensky, A, 2008. Numerical modelling of surface subsidence associated with block cave mining using a finite element-discrete element approach, PhD thesis, Simon Fraser University, Canada.